

Technical Peer Review of the DIII-D Five-Year Proposal

General Atomics, San Diego, April 22-25, 2003

Summary Report by Erol Oktay (USDOE/OFES)

Executive Summary

The DIII-D Five-Year Proposal submitted by General Atomics was peer reviewed by a Review Panel of ten expert scientists representing a wide cross-section of the international fusion community. The OFES charge to the Panel was to review the proposal with respect to (a) relevance of research, (b) quality of research, (c) performance of operations, and (4) costs for research and operations.

The stated mission of the DIII-D Program is “to establish the scientific basis for the optimization of the tokamak approach to fusion energy production.” The primary means to accomplish this mission is research on the tokamak concept to find the ultimate potential of the tokamak as a magnetic confinement system. The DIII-D program also contributes to the resolution of key enabling issues for making progress with various magnetic fusion concepts, and advances the science and technology of magnetic confinement on a broad front. The DIII-D program is basic science research with an energy goal. The major strengths of the DIII-D program are its highly flexible and well-diagnosed facility and its large collaborative research team drawn from the national and international fusion community.

The DIII-D five-year plan has been formulated to address the 5-10 year issues identified in the Integrated Program Planning Activity (IPPA) and to make major contributions to the ITER program. IPPA issues and ITER-related contributions, as well as the hardware and diagnostic upgrades required to achieve the scientific goals, are identified throughout the DIII-D proposal and were presented to the Review Panel during the on-site peer review of the proposal. The International Tokamak Physics Activity (ITPA) is the primary channel to connect DIII-D research to ITER and to the international fusion community, especially in conducting joint experiments among the world’s tokamaks within the ITPA/IEA coordination of implementation of ITPA high-priority research activities.

The Review Panel members provided individual reports on their deliberations. Their general finding is that the DIII-D research is relevant to national program goals as articulated in the IPPA and to burning plasma physics issues in support of future experiments such as ITER. The quality of research is excellent; it is world-class research at the forefront of areas such as AT physics, MHD mode control, and

transport studies. In performance of operations, GA is excellent in managing the program as the host laboratory and establishing an excellent system for collaborations as a national user facility. DIII-D has a successful record of completion of milestones. While the costs for research and operations appear to be reasonable, the proposed five-year funding profile is challenging. Many members summarized their impressions by stating that the DIII-D research program is going in the right direction and that it is the “model of a successful research project.”

The proposed DIII-D research program comprises three major research themes: advanced tokamak research, transport and turbulence, and mass transport. These themes are advanced by a set of cross-disciplinary research Thrusts and by the four Topical Science activities (transport, stability, heating and current drive, and boundary science). Contributions to burning plasma physics research in general and ITER in particular, are distributed among these efforts.

Details of the General Atomics presentations and a summary of the findings of the Review Panel are described in the present summary report.

I. Introduction

General Atomics (GA) submitted a Five-Year Proposal entitled *DIII-D National Fusion Program Research and Facility Operations* for the period of November 1, 2003, thru October 30, 2008. The total cost of the proposal is \$296,665,727. The technical component of this proposed Program Plan was originally drafted by the DIII-D Team for discussion at the National Tokamak Workshop in June 2002. The Team then prepared the final Program Plan, which in February 2003 was previewed by the DIII-D Program Advisory Committee for further advice to GA about the program direction. The three major DIII-D collaborators—PPPL, LLNL, and ORNL—prepared companion documents to describe their respective roles in the DIII-D program.

The OFES established an external Review Panel of experts, representing a broad spectrum of international fusion community, for technical peer review of the proposal. The members of the Panel (chaired by J. Van Dam) were:

- Benjamin A. Carreras Oak Ridge National Laboratory (Theory)
- Cary B. Forest University of Wisconsin (Tokamak Physics)
- David N. Hill Lawrence Livermore National Laboratory (SSPX)
- Jef Ongena Ecole Royale Militaire-Brussels (TEXTOR/JET)
- Masayuki Ono Princeton Plasma Physics Laboratory (NSTX)
- Douglass E. Post Los Alamos National Laboratory (Computational Physics)
- Steven A. Sabbagh Columbia University (NSTX)
- Michiya Shimada Japan Atomic Energy Research Institute (ITER Physics)
- James W. Van Dam University of Texas (Theory)
- Stephen M. Wolfe Massachusetts Institute of Technology (C-MOD)

The charge for the review is shown in [Attachment 1](#). In brief, the charge was to review the proposal in the following areas: (a) relevance of research, (b) quality of research, (c) performance of operations, and (d) costs for research and operations. The GA staff gave presentations during the first 1.5 days of the review to address the questions in the review charge. These presentations were followed by brief presentations from the major collaborators—PPPL, LLNL, and ORNL—to describe their respective roles in the DIII-D 5-year program.

In this summary report, the GA presentations are briefly discussed in Section II, and the Review Panel conclusions are summarized in Section III. The latter are based on the individual reports received from the ten members of the Review Panel. Although most of the panel members provided answers to the four questions in the charge, some members provided comments on the topical areas that were presented at the review. The present summary report therefore provides summaries for both of the following cross-cuts:

- Responses to charge questions, and
- Responses to presentations about topical areas.

Section IV of this report describes the review of cost and schedule details, which was conducted by a separate Cost Evaluation Board. Its members consisted of the following Department of Energy personnel:

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|------------------------------|-----------------------------------|
| • Mark Foster and Kim Abbott | Berkeley Site Office |
| • Louise Guilbault | DCAA Office at GA |
| • Greg Pitonak | PPPL Area Office (by mail review) |
| • Mark Yannello | Chicago Office (by televideo) |

II. Presentations by GA and DIII-D Collaborators

The agenda for the review is shown in [Attachment 2](#). The viewgraphs for the General Atomics and DIII-D collaborator presentations can be accessed through this agenda via hyperlinks. The GA presentations described the current status and five-year plans for Advanced Tokamak (AT) research, which is the major DIII-D Thrust area, and for the four Topical Physics areas of Stability and Disruption Physics, Heating and Current Drive, Confinement, and Boundary Physics. These were followed by consolidated presentations on Theory Program Coupling, Facility Plans, Diagnostic Plans, and Facility Management. Finally, Ron Stambaugh summarized the scope of the General Atomics tasks and its share of the cost.

The stated **mission** of the DIII-D Program is “*To establish the scientific basis for the optimization of the tokamak approach to fusion energy production.*” The primary means to accomplish this mission is research on the Advanced Tokamak thrust to find the ultimate potential of the tokamak as a magnetic confinement system. The DIII-D program also contributes to the resolution of key enabling issues for making progress with various magnetic fusion concepts, and advances the science and technology of magnetic confinement on a broad front. The major strengths of the DIII-D program are its

highly flexible and well-diagnosed facility and its large collaborative research team drawn from the national and international fusion community. GA has the responsibility to manage the facility operations and to lead the diverse international team in planning and executing the research program.

The DIII-D Team has identified **three specific technical focus areas** in which to make major advances during the next decade:

1. Advanced Tokamak (AT) physics basis for steady-state operation of ITER, Component Test Facility (CTF), and DEMO;
2. Transport resulting from plasma turbulence; and,
3. Mass transport in the scrape-off layer and divertor.

Ron Stambaugh described the **major accomplishments** during the past five years that have been made in the building blocks of AT physics (including, stabilization, active control of plasma profiles such as current, density, and temperature), disruption mitigation, and enabling technologies (including, gyrotrons, density control by divertor cryo-pumping, internal control coils for stabilization, and multi system for feedback control). The challenge in the coming years is the **integration** of different physics issues and plasma control techniques to demonstrate high-performance, steady-state plasma scenarios for ITER, CTF, and DEMO.

The DIII-D five-year plan has been formulated to address the 5-10 year issues identified in the Integrated Program Planning Activity (IPPA) and to make major contributions to ITER. The IPPA issues and the ITER-related contributions, as well as the hardware and diagnostic upgrades required to achieve the scientific goals in different areas, were identified throughout the presentations. The International Tokamak Physics Activity (ITPA) is the primary channel to connect the DIII-D research to ITER and the international fusion community, especially in conducting joint experiments among the world's tokamaks within the ITPA/IEA coordination of implementation of ITPA high-priority research activities.

In the first focus area, **advanced tokamak physics**, DIII-D has developed several steady-state scenarios and stationary “hybrid” scenarios to investigate the basis for ITER long-pulse discharges. (The hybrid ITER scenario refers to discharges with both inductive and non-inductive current drive.) Progress in AT physics research, as measured by the metrics in the following table, is expected to occur in three phases.

Metric	Description	2003	2005-2006	2009
		Scenario Development	Integration & Sustain	Optimization
f_{BS}	Fraction of bootstrap current	65 %	70 %	90 %
β_N	Normalized beta	~2.8	>4	~5
H	Confinement factor	2.5	2.5-3	3
f_{NI}	Fraction of non-inductive current	90 %	100 %	100 %
t_{DUR}	Discharge duration	2 sec	5 sec	10 sec

The ultimate goal is simultaneous achievement of the numerical targets in this table. The approach will be to increase the fraction of bootstrap current through the achievement of high β_N plasmas, which will require extensive profile controls, primarily through active feedback methods. Staged implementation of additional heating power and other upgrades, discussed below, are essential to achieve these progressive targets.

In the focus area of **energy transport** studies, GA is proposing that the DIII-D team take an international leadership role to investigate the underlying physics of turbulent transport. This work will require close coupling with other tokamak programs, with the theory and modeling community and diagnostic initiatives, and with the U.S. Transport Task Force. DIII-D already uses an extensive array of diagnostics, and new diagnostics are planned for investigating critical transport issues, such as electron transport and zonal flows.

The third area of focus, **mass transport**, is a broad area of research that ranges from boundary physics, power and particle control, and impurity transport, to plasma flow in the divertor, erosion and re-deposition of carbon, and tritium trapping. It involves extensive effort on density control, ELM physics, validation of computational models such as UEDGE, and new measurement techniques for spatial and temporal data on co-deposition of carbon on surfaces. LLNL—and, to a lesser extent, ORNL—are major contributors to this focus area.

The Review Panel heard extensive presentations on these focus areas and on the four topical physics areas, which provided details about the physics issues and rationale for the upgrades needed to accomplish the physics goals.

The **primary upgrade plans** include the following:

- Upgrade the ECH system to 9 MW/10 second capability in 3 stages (total cost about \$14.7 M)
 - 1) Purchase three new 110 GHz/1 MW/10-second gyrotrons to carry out experiments with 6 MW/10-second capability: ~ \$ 5.0 M. (The present system has three 1 MW/10-second CPI gyrotrons and three 1 MW/2-second Russian gyrotrons. The new gyrotrons would replace the three Russian gyrotrons.)
 - 2) Add two ECH transmission lines, initially to continue using two of the existing Russian short-pulse gyrotrons, and later to use 1.5 MW/10-second gyrotrons from the Technology Development program: ~ \$ 4.9 M.
 - 3) Purchase two 1.5 MW/10-second depressed collector gyrotrons: ~ \$ 4.8 M.
- Neutral beam system (\$5.3 M)
 - 1) Rebuild new ion sources: ~ \$1.3 M
 - 2) Rotate one beam line for balanced beam experiments: ~ \$4 M
- Divertor and first wall (\$9.0 M)
 - 1) Modify lower divertor outer baffle for pumping: \$3.8 M
 - 2) Modify upper divertor outer baffle and pump: \$4.3 M

3) Increase first wall thermal capacity: \$0.9 M

- Long pulse capability (\$2.0 M)
- Power supply modifications (\$2.9 M)
- Computer and data acquisition systems (\$3.9 M)
- Integrated plasma control system (\$3.7 M)
- Fueling and other smaller upgrades (\$1.8 M)

These upgrades add up to about \$43.3 M, which is included in the proposed \$179.751 M facility operations budget. Detailed information about the various budget elements is shown in the table below.

GA Costs (in \$K) of the DIII-D Five-Year Proposal (21-week schedule)

	04 (11 mo)	2005	2006	2007	2008	09 (1 mo)	Total
Res Ops	21,461	23,386	21,745	22,794	23,145	1,821	114,352
Fac Ops	30,485	42,030	40,406	34,119	30,449	2,262	179,751
							0
Total DIIID	51,946	65,416	62,151	56,913	53,594	4,083	294,103
							0
Int. Collab	497	514	533	501	520		2,565
Total Proposal	52,443	65,930	62,684	57,414	54,114	4,083	296,668
							0
Facility UG	6,939	13,847	13,049	6,764	2,604	71	43,274

GA also described the following three additional options, not included in the total proposal budget of \$296.669 M:

- Additional facility upgrades: ~\$ 27 M;
- Increased experimental operating time, to 25 weeks: ~\$ 6 M total for the 5-year period
- Site restoration at the completion of the DIII-D program: ~ \$57 M

The following annual budgets for the collaborators, funded directly from OFES, were proposed for the 5-year period:

Budget for DIII-D Collaborators (in \$K)

FY04 (11 mo)	FY05	FY06	FY07	FY08	FY09 (1 mo)	Total
11,745	14,519	15,336	14,541	13,400	1,011	70,552

The collaborator budgets include some hardware and diagnostic upgrades that are not included in the GA budget, except for the GA share of upgrade costs. (The GA budget of

\$114.3 M for research operations includes about \$11.1 M for additional collaborative activities such as subcontracts to universities, international collaborations, and support for incoming collaborations to DIII-D.)

The proposed budgets for GA and collaborators are higher than the current levels. It is understood that the GA total represents a ceiling for the Cooperative Agreement for the five-year period. The plans for the facility upgrades and research program are reviewed annually and funded accordingly. As a perspective, the GA contract ceiling for the present five-year period (November 1, 1998, through October 31, 2003) is \$245.6 M, whereas the actual funding will be about \$204 M.

III. Summary of Review Panel Comments

Overall, the Review Panel members were very impressed with the presentations about the DIII-D program and the five-year plan. Their general observations can be summarized as follows:

The DIII-D research is relevant to national program goals as articulated in the Integrated Program Planning Activity (IPPA) and to burning plasma physics issues in support of future experiments such as ITER. The quality of research is excellent; it is world-class research at the forefront of areas such as AT physics, MHD mode control, and transport studies. In performance of operations, GA is excellent in managing the program as the host laboratory and establishing an excellent system for collaborations as a national user facility. DIII-D has a successful record of completion of milestones. While the costs for research and operations appear to be reasonable, the proposed five-year funding profile is challenging.

Many members summarized their impressions by stating that the DIII-D research program is going in the right direction and that it is the “model of a successful research project.”

A. Summary of Panel Responses to Review Charge Questions:

1. *Assess the **relevance** of the proposed 5-year fusion **research** with respect to the goals of the U.S. fusion program as outlined in the Integrated Program Planning Activity, and in particular to the Burning Plasma Physics related studies in response to the recent U.S. decision to join the ITER negotiations. Is the research likely to accomplish its stated objectives? How well is the research coordinated with other national and international fusion research activities?*

The DIII-D program is clearly addressing some of the top issues identified by FESAC and IPPA. It has an important impact on ITER. The whole DIII-D program should put the U.S. in a strong position in the ITER negotiations. The proposed research objectives will

be accomplished if the funding is provided. Giving funding guidance over the five-year period could greatly help in optimizing the productivity of the program.

DIII-D contributions to burning plasma physics in general and to ITER in particular are distributed among the three cross-disciplinary research Thrusts (including, advanced tokamak physics, transport and turbulence, and mass transport) and the four Topical Science activities (transport, stability, heating and current drive, and boundary science).

The excellent track record of research planning and progress by DIII-D inspires confidence in the DIII-D team's ability to achieve its proposed objectives. The DIII-D program has made remarkable progress in the last five years that includes (1) the validation of ECCD as an off-axis source of current drive, (2) the stabilization of the resistive wall mode by plasma rotation, (3) the exploitation of new techniques for stabilizing neoclassical tearing modes, and (4) disruption mitigation by high pressure gas jets. All of these stand out as major scientific steps forward for the tokamak; the DIII-D team deserves to be recognized for leading the world in these areas. The DIII-D team has also made advances in other areas such as understanding of turbulent transport, which are also of great interest. These advances have been made possible by an excellent collection of diagnostics, flexible control tools, and an outstanding team of researchers.

The proposal for the next five years of research evidences a great deal of preparation. The research accomplished in the past five years and the work proposed for the next five years appears to be well coordinated with other research activities, both national and international.

2. *Assess the **quality** of the ongoing and planned **research**. Does the research proposed address science at the forefront of the field? Does the ongoing and planned research maintain a U. S. leadership position in key areas of fusion research? Does the proposed work provide for an adequate set of diagnostics, other necessary facility upgrades, interactions with theory and modeling, and collaborations involving a broad group of domestic and international users?*

The quality of the ongoing DIII-D research effort is excellent, and the Proposal for the next five years continues and builds on that excellence. The DIII-D programs in AT and MHD in particular are recognized as world leaders in the field. The proposed research in these areas would certainly serve to maintain and extend a U.S. leadership position in these key areas. Similarly, the proposed initiative in Transport Science would enhance an already strong program at DIII-D and lead to truly cutting edge science. The proposed enhancements to the already exceptional DIII-D diagnostic capability are appropriate and are driven by the requirements of the proposed research. Similarly, the facility upgrades, in the areas of heating and current drive systems, substation upgrade, and long-pulse capability are driven by the research goals.

Close coordination between experiment and theory/modeling has been a hallmark of

DIII-D research. The present Proposal emphasizes the interaction of theory and simulation with experiment in all aspects of the planned work. The initiative in Transport Science is particularly exciting in this regard, motivated as it is by the ability of modern codes to simulate all the essential turbulence physics needed for detailed comparison with experiment.

The strength of the DIII-D Program arises from the effective integration of national and international collaborations in experiment, theory, modeling, and technology into a coherent, nearly seamless team effort. The effectiveness of the DIII-D approach in this regard is unsurpassed, and is a model for collaborative scientific endeavors.

3. *Assess the current level of **performance** of facility **operations**. Are milestones being met? Are planned operating, maintenance, repair and upgrade schedules being achieved? Are environment, safety, health and quality assurance matters being addressed appropriately? Assess the program's governance practices and the performance of the direct program management as well as the support provided from the host institution.*

DIII-D operates with a high level of availability, typically over 70%. Milestones are being met in a timely manner. There is a well-defined preventive maintenance schedule involving over 1700 pieces of equipment, requiring nearly 7000 hours annually. Safety is taken seriously, as evidenced by the excellent safety record compiled over the past several years.

Experimental runtime allocations to each of the Topical Science Areas and Thrust Areas are determined by a top-down process involving the Research Council (48 members, drawn from the collaborating institutions and representing all the scientific divisions), a smaller Executive Committee, and ultimately the Program Director and his Deputy. Within the allocations, specific experiments and program sequences are determined in a bottom-up approach, beginning with the Opportunities Forum (brainstorming session) and refined in a series of team meetings and discussions. National and international collaborations are coordinated through the Fusion Facilities Coordinating Committee (FFCC) and ITPA/IEA structures, respectively. A Program Advisory Committee (PAC) meets annually to provide advice and community feedback to the Program Director. Facility Operations are overseen by the Assistant Program Director and are divided among Experimental Science, Heating and Current Drive Systems, and Tokamak Systems, each reporting to its own manager. While the management and organizational structure seems somewhat complicated, the effectiveness of the system is evidenced by the excellent results, particularly the successful integration of so many different institutions, including large and small collaborators. Basically, the system works well.

The host institution (General Atomics) provides facility infrastructure in support of the research program. Most recently, GA enlarged the building to accommodate the new ECH vault and additional workspace for technicians (an 8000+ square foot, two-story addition). At the same time the DIII-D conference room was enlarged.

The Review Panel was concerned about an issue that the DIII-D management has been facing for years, namely, the process by which experimental proposals are accepted. As the request for proposals has been directed to a broader audience, their number has increased. On the other hand, experimental time has not increased, and in fact it is well below what is desirable for such a facility. Consequently an increasing number of proposals have been rejected. Even if the machine time were to be doubled, there would still be a large number of unsatisfied scientists who spent time preparing reasonable proposals that were not accepted. Whether this issue can be resolved is unclear.

4. *Assess the reasonableness of the proposed **costs** for fusion **research and operations**. The cost review should be done at a summary type level, examining major items and projections from ongoing operational experience.*

The proposed costs appear to be in alignment with the proposed scope of work. The upgrade schedule is heavily front-loaded, resulting in a cost peak in FY 2005-06 and a corresponding peak in personnel, principally contract labor and engineering support staff for fabrication and installation activities. This costing profile seems somewhat unrealistic. Capital spending, while increased from recent years (when it was essentially non-existent), appears small in relation to other costs, and again decreases in the out years. The low level attributed to capital expenses may be due to local definitions, and, in any case, procurements of all types are apparently overhead free. On the other hand, given the stated intent to propose continued operation of the DIII-D facility beyond 2008, the paucity of upgrade funding in the last year of the proposal seems inconsistent. On the other hand, given the unlikelihood of actually obtaining the proposed funding profile, this may simply be the recognition that under likely budget scenarios, the upgrades included in the present plan will not be completed until after FY 2008.

The committee, mindful of the possibility of a flat OFES budget, requested a prioritized list of the upgrades, which was provided by the GA management. (This prioritized list will be described in the following subsection.)

B. Summary of Recurrent Issues

Briefly summarized below are some of the recurrent issues that arose during the panel deliberations.

1) Program priorities in the event of a reduced budget

Since that the proposed DIII-D budget is considerable higher than the current level, the Review Committee asked GA to identify priorities. The prioritized list from GA was as follows:

1. Increased run time (21 weeks)
2. Six 10-second/1 MW gyrotrons (acquisition of three new gyrotrons)
3. Fast ion profile diagnostic and divertor CER
4. Transmission lines for 8 gyrotrons (building two new lines)

5. Fast wave system upgrade
6. 138 kV prime power substation
7. Lower divertor pumping
8. Counter beams
9. Long-pulse 10-second upgrades
10. 9 MW operation for ECRH (acquisition of two new 1.5 MW gyrotrons)
11. Upper divertor upgrade

Ron Stambaugh clarified that the DIII-D team places importance on the implementation of the full 9 MW of ECH power, which is only lower in the priority list since it can only occur after progress with the development of the 1.5 MW depressed collector gyrotrons in the VLT program. This development supports both the DIII-D program in the near term and ITER in the long term.

2) Plans for rotation of one beam line for balanced beam operation

Several of the scientific presentations emphasized the important benefit of rotating one of the beam lines to counter-beam injection in order to avoid plasma rotation with balanced beam operation. Halting the rotation aids the study of the stabilization of Resistive Wall Modes. Such stabilization can even now be partially achieved by “magnetic breaking” provided by the external C-coil. However, it is preferable to achieve this objective with balanced beams, so as to decouple the effects of the C-coil from those of the stabilizing internal coils. Furthermore, counter-beam injection is currently necessary for ELM-free QH and QDB discharge scenarios, and it would also improve several diagnostic capabilities, such as the MSE system. In fact, the decision on which particular beam-line to rotate is primarily driven by diagnostic requirements, since rotating a different beam-line would be a little less costly.

The Review Panel toured the DIII-D experimental facility to get a feel for the work involved in rotating one of the beam lines, which will cost about \$4 M. The main expense is in the re-location of a large number of diagnostics and power feed lines for the poloidal field coils. Several Panel members noted that it would be useful to do this upgrade earlier rather than later (presently it is scheduled for 2006), although they understood GA’s dilemma with including this large budget item in their funding profile. GA estimated that it would take about 3-5 months to rotate the beam line, after extensive planning and preparation.

3) Single null versus double null operation

Although GA emphasized that the DIII-D program will make substantial contributions to ITER physics, the presentations seemed to suggest that most of this work would be done in the double-null configuration for increased triangularity and plasma performance. The DIII-D proposal includes substantial upgrade funds to improve pumping in the double null configuration. Review Panel members questioned the GA presenters about this apparent conflict between the ITER and DIII-D configurations. Tony Taylor explained that the ITER-relevant experiments in DIII-D would be first carried out in single-null operation, and that then these results would be compared with those in double-null

experiments to study the benefits of high triangularity in increasing power output. Double-null operation could be a choice for post-ITER facilities, such as DEMO.

Some of the modifications in the divertor baffles, discussed earlier in the primary upgrade plans, will increase the flexibility of DIII-D for operating in higher triangularity plasmas with pumping, which is essential for investigating AT plasmas.

4) Pedestal physics

Although the DIII-D program has a Thrust area on pedestal physics, the description of the issues in this area was spread over several other scientific presentations. Some Panel members indicated that pedestal physics should have higher visibility in the DIII-D program and in the presentations. Some Panel members even suggested that pedestal physics should be a fourth scientific focus area during the next five years, along with AT physics, turbulent transport, and mass transport.

5) Computer cluster for transport modeling studies

An item in the DIII-D proposal is to acquire a 128-processor Linux computer cluster system for transport modeling studies with a particular code. The Review Panel recommended that this system should be an off-the-shelf item, one step behind the state-of-art to avoid developmental issues, and it should be paid for under the GA theory program, probably with some contribution from DIII-D. The procurement of this system, which would cost about \$250 K, is planned for FY 2006 or thereabouts. The Panel urged GA to purchase it earlier and to have the system be a fusion resource for more than one group or one program. Vincent Chan explained that, because the sharing software for such clusters is not well developed, it is most efficient if the cluster is arranged to run a particular code for a limited number of users.

6) Mass transport

On the subject of mass transport, the Panel's attention focused on carbon migration and tritium. Some concern was raised about the relevance of these topics to the DIII-D program. The presentations clarified the broad nature of this focus area. Several Panel members that DIII-D research on power and particle control not be diminished, since this will gain importance with the U.S. participation in ITER.

7) Transport studies

Several Panel members noted that the proposed transport initiative would require extensive interactions with the community, for which the DIII-D team is eminently qualified. However, it was noted that the DIII-D team will need to listen not only to its own circle of theorists, but also to others, in order to maintain a leadership role in this area.

C. Summary of Debriefing Reports by Panel Members:

The following are brief highlights of the comments that were made in the debriefing reports given by the Review Committee members. (These debriefing reports varied widely in style and content.)

1) Panel chair's summary of the overall proposal:

- *Relevance of Research*
 - Research is relevant to national program goals (IPPA, Burning Plasma, etc.,)
 - Excellent track record of research planning and progress inspires confidence in DIII-D ability to achieve its proposed objectives
- *Quality of research*
 - Forefront, world-class research (e.g., AT physics, MHD mode control, transport studies, ...)
- *Performance of operations*
 - Excellent management by the host (GA)
 - Excellent system for collaborations as a national user facility
 - Successful completion of milestones
- *Costs for research and operations*
 - Appear to be reasonable
 - Proposed five-year funding profile is challenging

The chair repeated comments by several Panel members to the effect that the DIII-D program is on the right track and that it is a model of a successful fusion project.

2) Debriefing report about AT physics:

- The DIII-D program has made outstanding contributions on many aspects of magnetic fusion research, including the development of advanced tokamak physics. Its strength resides in close national and international collaboration among experiments, diagnostics, theory, and modeling, supported by excellent enabling technologies, which makes a model example of a successful fusion research project.
- The heating power normalized by the major radius is the highest in the world and will approach the value of ITER with the proposed upgrade in heating and current drive. This is a unique opportunity to investigate power and particle issues for ITER.
- Four physics issues to investigate in DIII-D that could improve the feasibility of ITER achieving its mission of $Q > 10$ in the inductive operation are: pedestal physics; type-I ELM physics and ELM mitigation methods; neoclassical tearing mode stabilization; and disruption prediction and mitigation, including neutral networks and impurity gas injection.

3) Debriefing report about boundary physics

- Should make “understanding the pedestal” a fourth major research area
- Important divertor diagnostics are proposed; however, should also increase the resolution of other measurements
- The focus on “material transport” might lead to neglect of SOL model validation

4) Debriefing report about stability

- DIII-D stability research continues to excel. Examples are active stabilization of resistive wall modes, neoclassical tearing mode stabilization, disruption mitigation, and error field effects.
- Relation to ITER will need to be more explicit and prioritized
- The counter-beam upgrade should not be indefinitely deferred.
- Stability research would benefit from increased run time (double the present level)

5) Debriefing report about confinement and transport

- Objective is very ambitious, but this group is eminently qualified to take such a challenge
- Active collaboration with other theory groups will need to be enhanced
- The quality of the proposed research is very high
- Success of this proposed activity will require
 - Counter injection beam
 - Implementation of several diagnostic proposals
 - Sufficient experimental time
 - Effective computational facility
- Maintain active links with ITER, and emphasize ELM studies

6) Debriefing report about electron heating and current drive

- EC heating and current drive is a vital tool for AT research, which requires current profile control, transport studies, and active MHD control
 - Fully endorse GA high priority to implement the 6 MW/10-second system
 - DIII-D leads the world in experimental validation of ECCD models
 - DIII-D is at the forefront of NTM stabilization with ECCD; this research is supportive of and necessary for ITER
- Fast wave heating and current drive play an important role in AT physics, transport studies, and MHD experiments
 - Coupling to H-mode plasmas remains a research issue
 - Support re-starting this system, although it may be less important than other systems in a reduced budget scenario
 - Good collaboration among GA, PPPL, and ORNL both in physics and in hardware upgrade.

7) Debriefing report about theory program coupling

- GA theory group is well integrated with the experimental program
- The combining of modeling capabilities into integrated simulation packages is very ambitious and time intensive
- Excellent theory/simulation support and analysis for DIII-D experiments
 - MHD computations for active control of NTM and RWM instabilities and for ELM modeling
 - Transport simulation capabilities have developed greatly
 - LLNL making good progress in boundary physics; UEDGE-BOUT integration is worthwhile

- ECCD modeling and experimental comparisons (by GA, ORNL, PPPL, CompX) are commendable
 - Collaborations with other theory groups (e.g., LLNL, Chalmers, Culham, PPPL) have been productive
- Computational resources are inadequate

8) Debriefing report about facility and diagnostics plans

- Facility upgrade plans are well thought out and consistent with five-year research plan
 - Front-loaded facility upgrade plans are challenge for budget profile and manpower requirements
 - ECH upgrade is supported by the Panel
 - Counter-beam project is popular; understand the challenge
- Diagnostic capability is state of the art and world-class
 - Strong university role in DIII-D diagnostic program is an excellent success story for this major national fusion science facility
 - Diagnostic upgrade plan is understandably front-loaded

9) Debriefing report about facility management and cost

- GA does an excellent job as the host in this challenging job of managing and planning the program, and integrating collaborative experiments and hardware contributions
- Kudos for a web-based trouble report system – a model for the community
- Good preventive maintenance program
- Safety taken seriously--very good safety record
- Milestones are 75 % on time; others are 1-2 months late
- Issues concerning priorities:
 - Fast-ion profile diagnostic priority is perhaps too high
 - Counter-beam priority is perhaps too low
- Runtime backlog of 5 years is a major issue
- Panel supports 21-week operating schedule.

10) Debriefing reports about three major collaborating laboratories

Three members of the Review Panel commented on the collaboration research plans of the three major collaborating laboratories: LLNL, ORNL, and PPPL. Their comments were complimentary. The presentations by the collaborators were useful for describing the DIII-D program from a different perspective and for understanding the benefits that the major laboratories bring to the program. The collaborators are well integrated into a coherent DIII-D program, without rigid barriers between tasks and the roles of the collaborators and the host institution. The collaborators have as much access as the GA staff to undertaking key research roles and presenting DIII-D results. GA was commended for successfully managing the collaborations carried out by a diverse group of scientists.

IV. Cost and Schedule Review

During the technical presentation, the Review Panel was presented with a high-level description of the proposed budgets and schedules. Panel members made general comments to the effect that the proposed costs are realistic only if the OFES program receives an increase in connection with its ITER involvement. Ron Stambaugh expressed his optimism that opinions about fusion and ITER within the Administration and Congress are changing in the right direction and that there may be an opportunity for the program budget to increase. Both GA and the Review Panel agreed that 21 weeks of operation should be the highest priority. GA provided a prioritized list for implementing the proposed hardware upgrades under reduced budgets.

After the conclusion of the Review Panel, the DOE Cost Evaluation Board discussed the details of the budget during a three-hour session with Ron Stambaugh and Keith Shoolbred from GA. This discussion included topics such as overhead costs, manpower mix and costs, travel plans, etc. No surprises emerged during these discussions. The Cost Evaluation Board prepared a report concerning cost issues for input to the contract negotiators.